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Title: Result of On-board Experiments of Increased Amount of Charge Injection for XIS1
Category: XIS
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Summary

Context: The XIS onboard Suzaku has proven that charge injection (CI) is quite effective to rejuvenate the performance of X-ray CCD detectors, which are subject to rapid degradation in the orbit under a constant dosage of cosmic-ray radiation. Since we started the CI operation in 2006, the rate of decrease in the charge transfer efficiency has been markedly alleviated. The rate is, however, larger for the back-illuminated (BI) sensor (XIS1) than the other front-illuminated (FI) sensors (XIS0, 2, 3), because we decided to inject less amount of charges (2 keV equivalent) for the BI sensor than the FI sensors (6 keV equivalent) not to sacrifice its superior low energy performance.
Aims: We revisit the decision made in 2006 in response to the performance changes since then. We examine if increasing CI amount to 6 keV equivalent for the BI sensor has scientific merits as of 2010.
Method: We conducted a series of observations with 2 vs 6 keV equivalent charges for selected targets, compared the improvements, and identified possible drawbacks by the change.
Results: With the increased CI amount, we found that the high-energy response has improved prominently with a negligible loss in the low-energy performance. We encountered a significant telemetry saturation, however, due to the leakage of injected charges during the charge transfer. We plan to mask these artificial events with new clock patterns, which will take some time. We conclude that the CI amount for BI sensor should be increased to 6 keV equivalent for observations once the new clocks are ready.

1 Background

The X-ray Imaging Spectrometer (XIS) is an X-ray instrument onboard the Suzaku satellite, which is in operation for 5.5 years. The XIS is equipped with four X-ray CCD devices (XIS0–3) capable of imaging-spectroscopic observations at a 0.2–12 keV energy range with a moderate energy resolution of $R \sim$30–50. Three CCDs are front-illuminated (FI) devices (XIS0, 2, and 3), while the remainder is a back-illuminated (BI) device (XIS1). The FI and BI sensors are superior to each other in the high and low energy response, respectively.

X-ray CCD devices are subject to degradation in the orbit. One of the outcomes is the increase of charge traps under constant radiation in the space environment. This results in the decrease in the charge transfer efficiency (CTE), which leads to the degradation in the energy resolution.

The XIS has a function to precisely monitor and mitigate this effect. For monitoring, each sensor has ^{55}Fe calibration sources at two corners in the far-side of the readout. For mitigation, charge injection (CI) is implemented. Electrons are injected artificially from one side of the chip and are read out along with charges produced by X-ray events. Artificial charges are injected periodically in space (one in 54 rows), which fill in charge traps sacrificially, and thereby alleviate the decrease in the CTE for charges by X-ray events.

Fig. 1 shows the long-term trend of the measured peak energy and width of the Mn I Kα line (5.9 keV) from the ^{55}Fe calibration sources. The CI technique was put into routine operation since the middle of 2006 and has brought a drastic improvement. At the start of the CI operation, the XIS team decided to inject the amount of charges equal to the amount produced by a 6 keV X-ray photon ("6 keV equivalent") for the FI devices and a smaller amount ("2 keV equivalent") for the BI device. The

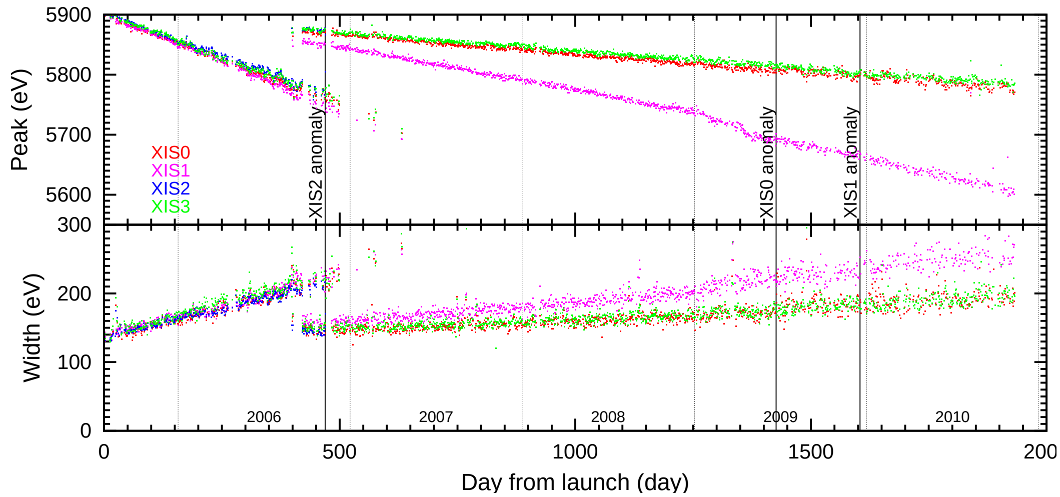


Figure 1: Trend of peak energy and width of Mn I Kα emission from ^{55}Fe calibration source.

smaller amount is due to the expected increase in noise in the low energy end of the spectrum, at which the BI device has an advantage over the FI device.

The situation has changed since then. The accumulation of the contaminating material on the surface of the CCDs made the low-energy advantage of the XIS1 less prominent. The CTE for the BI device decreases at a faster rate. As a consequence, the astrophysically important lines of Fe XXV (6.7 keV) and Fe XXVI (7.0 keV) are no longer resolved. The XIS team revisited the 2006 decision and started to take steps to judge whether the CI increase to 6 keV equivalent is beneficial for XIS1.

In 2010, we conducted a series of onboard experiments to evaluate the performance improvements and possible side effects of the CI increase for the XIS1. This article summarizes the results and argue for the routine operation of the increased CI of 6 keV equivalent starting from the AO6 cycle.

2 Data Acquisition

Table 1 summarizes the data set obtained in the experiment. We mainly used E0102–72 and Cygnus Loop, super-nova remnants with a line-dominated soft emission, to measure the low-energy response, and the Perseus cluster, a cluster of galaxies with extended hard emission, to measure the high-energy response. We did not use ^{55}Fe data for the CI=2 vs 6 keV comparison because they are too weak to use within the limited telescope time allocation for XIS calibration observations.

3 Results

3.1 Image

Fig. 2 shows the frame dump images taken with the CI=4, 6, and 8 keV (data ID #1 in Table 1). All images appear healthy. The column-to-column variation is more apparent for smaller amount of CI.

3.2 High-energy response

High-energy response was checked with a comparison data set of data ID #5 and #6 (Table 1) using strong Fe XXV and Fe XXVI emission lines from the Perseus cluster. The emission is pervasive across the entire XIS1 field of view. Fig. 3 compares the result between CI of 2 vs 6 keV. The peaks are noticeably higher and narrower for the CI=6 keV data with a 33% improvement in the FWHM.

Table 1: Data set.

ID	Target name	Seq. number	Obs. date	$t_{\rm exp}$ (ks)	Comment
1	CYGNUS_LOOP_P8	105007010	2010-06-11	10	Frame dump w. CI=4, 6, 8 keV.
2	E0102-72	105004020	2010-06-19	20	CI=2 keV.
3	E0102-72_1_4_WIN	105005010	2010-06-19	20	CI=2 keV.
4	E0102-72_PSUM	105006010	2010-06-20	40	CI=6 keV. Data lost for DR overwritten.
5	PERSEUS	105009010	2010-08-09	30	CI=6 keV.
6	PERSEUS_1_4_WIN	105010010	2010-08-10	30	CI=2 keV.
7	E0102-72_PSUM	105006030	2010-08-29	40	CI=6 keV. Heavy telemetry saturation.
8	E0102-72	105004040	2010-10-26	20	CI=6 keV. Slight telemetry saturation.
9	E0102-72_PSUM	105006020	2010-12-07	40	CI=6 keV. Lower event thres = 35.
10	E0102	105004050	2010-12-09	20	CI=2 keV.
11	E0102_1_4_WIN	105005020	2010-12-09	20	CI=2 keV.
12	CYG_LOOP_P8_6	105007020	2010-12-22	5	CI=6 keV.
13	CYG_LOOP_P8_2	105007030	2010-12-23	5	CI=2 keV.
14	PERSEUS	105009020	2011-02-03	40	CI=2 keV.
15	PERSEUS_1_4_WIN	105010020	2011-02-02	20	CI=2 keV.
16	PERSEUS	105027010	2011-02-22	40	CI=6 keV.
17	PERSEUS_1_4_WIN	105028010	2011-02-21	20	CI=6 keV.

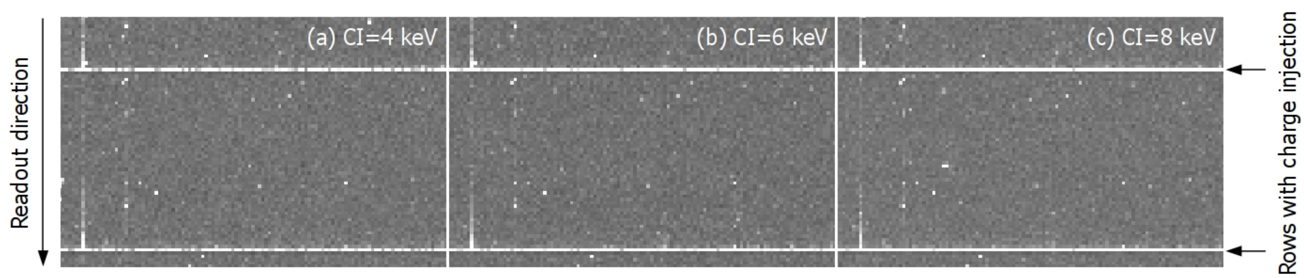


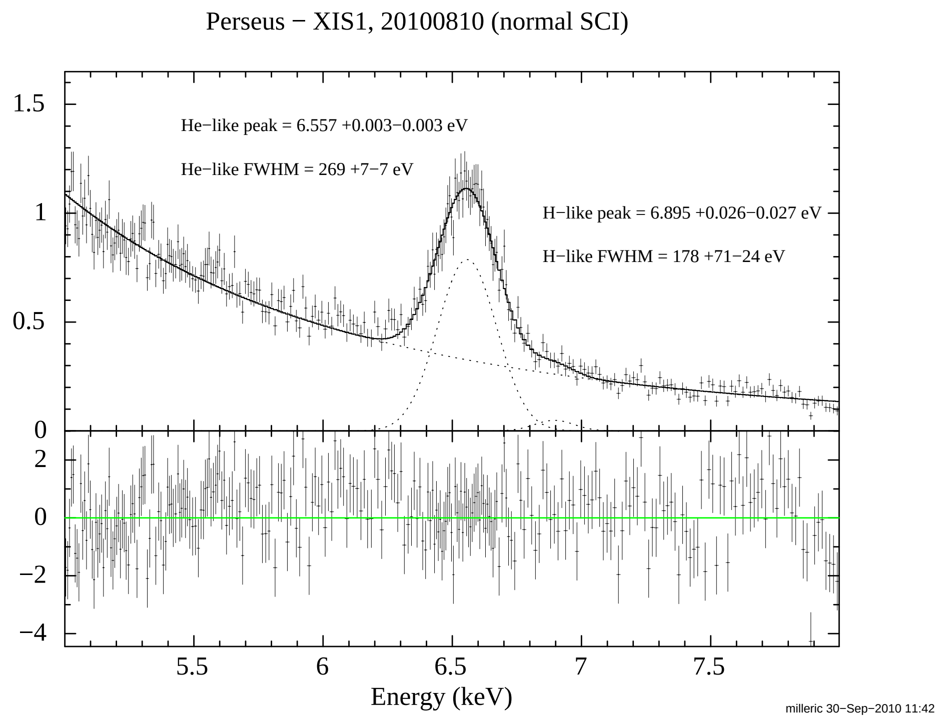
Figure 2: Enlarged view of frame dump images with different amount of CI.

3.3 Low-energy response

Low-energy response was examined by comparing two E0102–72 spectra (#9 and #10). The spectra were accumulated from the central part of the CCD (segments B and C). Figure 4 shows the result of fitting by a phenomenological model of a power-law continuum (Γ for photon index and $N_{\rm PL}$ for normalization) plus numerous emission lines attenuated by the interstellar photoelectric absorption with a column of $N_{\rm H}$. The width of the lines were thawed collectively for all the lines. The width and the constant value for the entire spectrum were thawed independently for the CI=2 keV and 6 keV data, while other parameters were derived from the CI=6 keV spectrum and fixed for the CI=2 keV spectrum. The detector response of a zero width was used for this fitting. Table 2 summarizes the result, in which we see some improvements from the 2 keV to 6 keV data. However, this change is within data-to-data scatter in the long-term development of the data.

3.4 Telemetry saturation and countermeasures

We encountered a significant telemetry saturation while we were observing E0102–72 with CI=6 keV (data ID #7 and #8 in Table 1). This was caused by a combination of (a) reduced telemetry bandpass



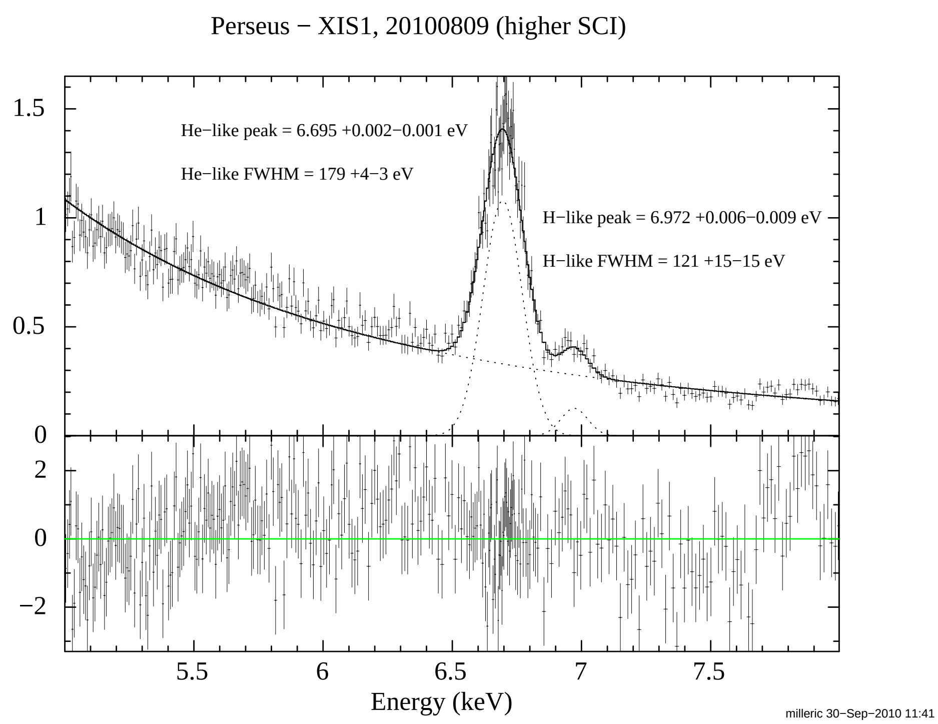
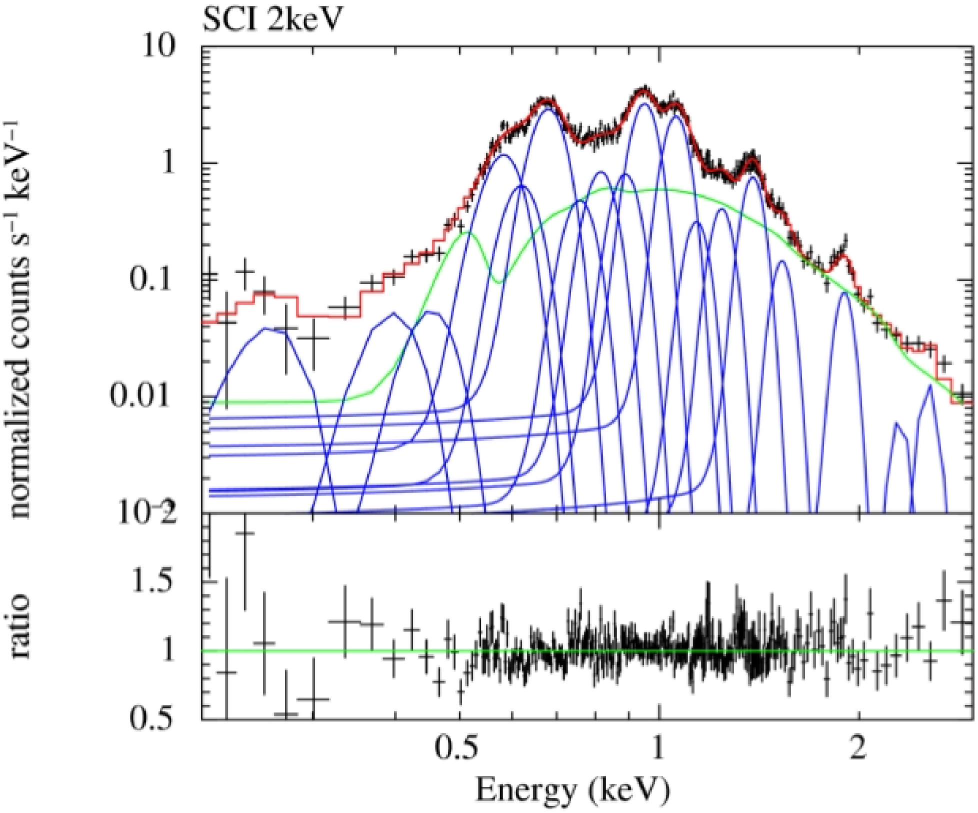


Figure 3: Comparison of Fe XXV and Fe XXVI lines from the Perseus cluster with the CI of 2 keV (top) and 6 keV (bottom).



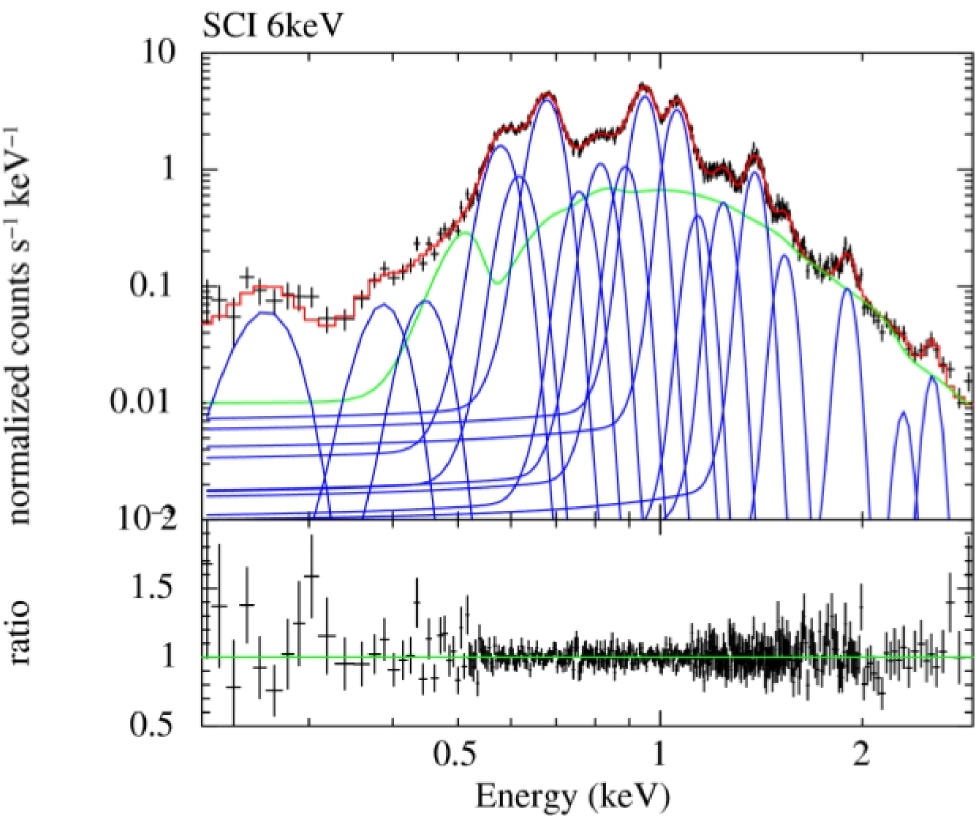


Figure 4: Result of fitting with a phenomenological model of the E0102–72 spectrum with the CI of 2 keV (top) and 6 keV (bottom).

Table 2: Fitting result of E0102–72 spectrum.

Parameter	Unit	CI=6 keV	CI=2 keV
Constant		1.0	0.89
$N_{\rm H}$	10^{21} cm^{-2}	5.6	5.6
Γ		5.3	5.3
$N_{\rm PL}$		1.2×10^{-2}	1.2×10^{-2}
σ	(eV)	1.5×10^{-2}	2.5×10^{-2}

in weekends, (b) increased artificial events due to increased CI amounts, and (c) gradual increase in non X-ray background of XIS1.

Figure 5 shows the rate of telemetry and the elevation from the Earth are shown as a function of time for the data ID #8. The telemetry is saturated in some time intervals.

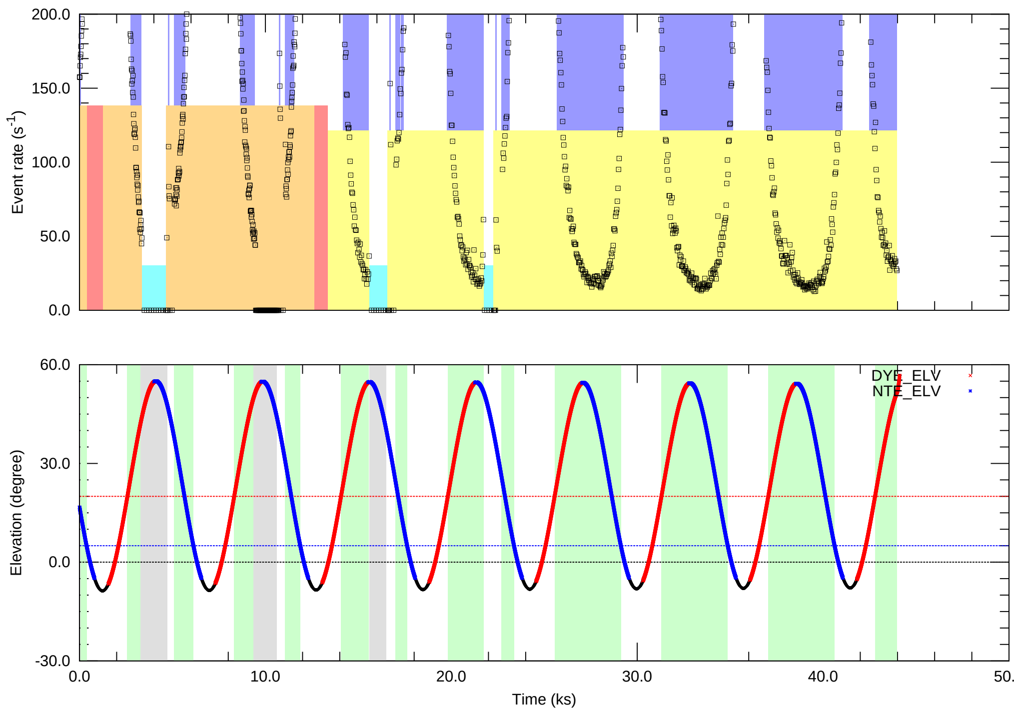


Figure 5: Telemetry rate (upper) and elevation from the Earth (bottom) as a function of time in the E0102–72 data taken with the CI amount of 6 keV in a week day. In the upper panel, the data rate is shown with different colors: red (super-high), orange (high), yellow (medium), and low (cyan). The hight of the bands indicates the telemetry limit. The time intervals of telemetry saturation are shown with blue bands. In the lower panel, the SAA is shown with grey, while the good time intervals by the standard screening criteria are shown with green bands.

Figure 6 shows the rate of telemetry as a function of time separately for the night earth and day earth elevations. Even at high elevations, the data rate exceeds the telemetry limit, resulting in an effective loss of observing time. The loss is reduced by raising the low event threshold from 20 (left panel) to 35 (right panel), but this does not solve the issue completely. Further increase of low event threshold cannot be accommodated considering its scientific impact.

The increased telemetry is mostly due to leakage of injected charges. They are localized in the image. These lines can be masked to suppress artificial events onboard by introducing a new set of

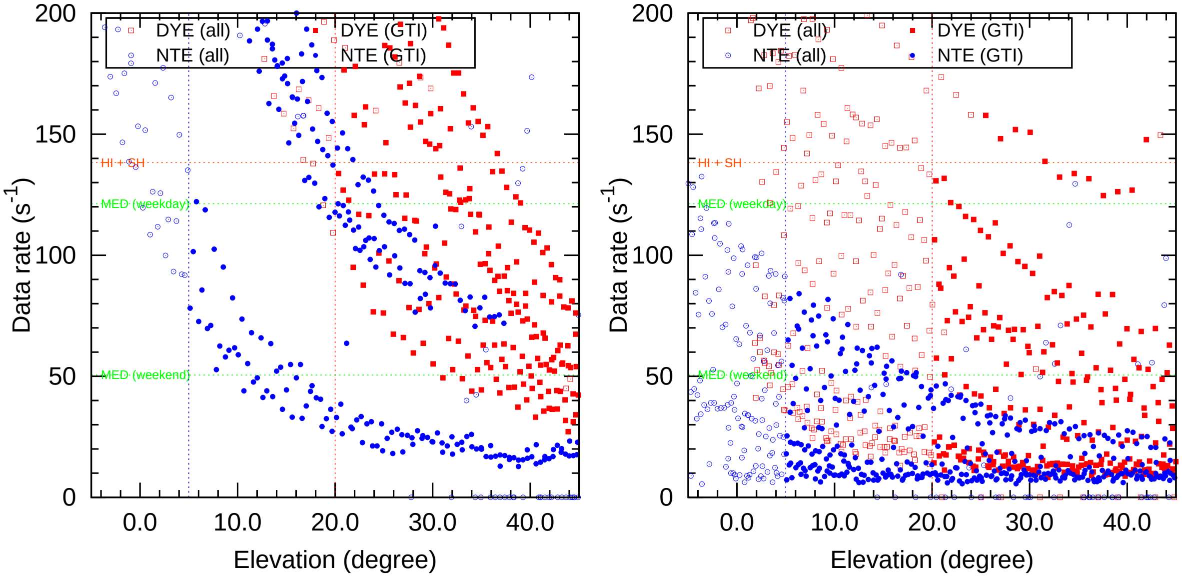


Figure 6: Telemetry rate as a function of elevation angle from the night and day Earth for CI=6 keV low event threshold of 20 (left, data ID #8) and 35 (right, data ID #9). The data in all times are shown with open symbols, while those only in the good time intervals with the standard screening criteria are shown with filled symbols.

CCD driving clocks. This will take some time for the development.

4 Conclusion

With increased CI amount from 2 to 6 keV equivalent the response improves significantly both in the high-energy bands. The telemetry saturation is encountered, with can be alleviated by introducing a new clock pattern to mask the charge leakage. This will be put into operation some time during the AO6 period.